Inferring Atmospheric Turbulence Structure Using Synthetic Aperture Radar Images Of The Ocean Surface

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LONG-TERM GOAL

My long-term goal is advance our abilities to remotely sense the properties of the marine atmospheric boundary layer, including mean wind speed and direction, the depth of the boundary layer, and the spatial distribution of atmospheric turbulence and associated fluxes, using synthetic aperture radar (SAR).

SCIENTIFIC OBJECTIVES

My first objective for this year was to finish the analysis of two data sets (ONR-MBL/ARI and Shoaling Waves) made up of simultaneous in situ turbulence measurements and SAR imagery. The scientific goal is to see what atmospheric information I could extract from the SAR image and verify with the in situ data. My second objective was to submit three papers based on this analysis (Mourad et al, 1999a,b; Vandemark et al., 1999). My third objective was to complete and submit two papers started the first year. One of these (Moller et al, 1999) is a comparison of low grazing angle radar backscatter and low wind measurements taken with the UMASS FOPAIR system – an X-band radar imaging system. The other paper is a review of atmospheric turbulence that can be imaged by synthetic aperture radar of the Ocean Surface (Mourad, 1999a). My fourth objective was to arrange with Paris Vachon of the Canadian Remote Sensing Center for RADARSAT-SAR images to be captured during two pilot studies for the Shoaling Waves Initiative and the main experiment, to occur this November 1999.

APPROACH

My approach for the first objective is simultaneous SAR image analysis (for extracting hypothetical atmospheric-turbulence signatures) and time-series analyses of the presumed wind forcing of those signatures. (The time series were captured by the NOAA LongEZ that flew during the SAR overpass.) The analysis of images includes many different kinds of filtering, smoothing and averaging procedures. The analysis of time series includes "quadrant analysis" and spectral (Fourier and wavelet) analysis. The results of this work is three submitted papers, based on SAR-image analysis, analysis of in situ turbulent time series, and analysis of radar and laser altimeter time series captured by the LongEZ simultaneously with the time series and SAR image. For my third objective (part 1) I worked with Dr.

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Delwyn Moller of JPL to analyze existing data that allows the comparison of low grazing angle radar backscatter images of the ocean surface off of Duck, NC with simultaneous wind speed and direction data under light wind speed conditions. For the second part of my third objective, I summarized the literature that deals with SAR imaging of the ocean surface for atmospheric phenomena. For my fourth objective, Paris Vachon and I have identified SAR images that will be collected simultaneously with LongEZ boundary-layer flights.

WORK COMPLETED

The majority of my work product is in the form of papers. The first paper is a review paper on extracting information on atmospheric turbulence from SAR imagery (Mourad, 1999a). This is now published. The second paper compares low grazing angle backscatter measurements with simultaneous measurements of wind speed and direction under low wind speed conditions (Moller et al., 1999). This paper is now submitted. The third paper is analysis of the Shoaling Waves Pilot study data set – in particular its SAR image and attendant turbulence measurements (Mourad et al., 1999). This is now submitted. The fourth paper is also analysis of the Shoaling Waves Pilot Study data set – in particular, its turbulence measurements and simultaneous laser and Ku-Band radar altimeter data (Vandemark et al, 1999). This paper is now submitted. The fifth paper summarizes research to date that seeks to extract fine-scale wind fields from SAR imagery, again based on the Shoaling Waves Pilot study data. This peer-reviewed paper is in press (Mourad et al, 2000). The sixth paper is with Dr. Bernard Walter of NWRA on the analysis of the ONR-MBL/ARI data set – in particular its SAR image and attendant turbulence measurements (Walter et al., 1999). This will be submitted this fall. I've also made two presentations (Mourad, 1999b,c).

RESULTS

One central result of the Shoaling Waves Pilot Study is the identification, for the first time definitely, that SAR "streaks" can be the signature of atmospheric roll vortices. The second central result is the realization that the rolls appear to be generating mesoscale variability in the surface wave spectrum, that is, SAR images both the instantaneous wind field and the time-averaged one, at least for the case of rolls. These results are reported in (Mourad et al, 1999; Mourad et al, 2000). Also, Vandemark et al (1999) show using simultaneous in situ turbulence measurements and aircraft-based radar altimeter and laser data that spatial variations in ocean surface roughness and wave slope from O(cm) to O(m) are due to the same atmospheric roll vortices that cause the SAR streaks. Moller et al (1999) report the first field-based observation of a critical wind speed associated with the onset of wind-driven gravity capillary waves of sufficient strength to cause significant radar backscatter at low grazing angles. There are two such speeds, one relevant for rising winds, the other for falling wind conditions. Walter et al (1999) present a case where the SAR streaks and atmospheric roll vortices do not appear to manifest the identical spatial scales. Instead the relationship between turbulent forcing and SAR imagery is more along the lines of the mutiscale roll vortices of Mourad and Brown (1990), where the shorter scales show up in the SAR image, with hints of the longer roll-vortex scale dominant in the time series.

IMPACT/APPLICATION

SAR images that contain streaks can be used to infer boundary layer properties such as mean wind speed and direction, with further refinement of existing algorithms. There is also promise that surface layer turbulence statistics may also be extracted from SAR images (see the independent work of Young and of Sikora). But, the relationship between SAR streaks and atmospheric turbulence can be more complicated than a 1-1 relationship: care is always advised. Also, from Moller et al (1999) we have evidence of hysteresis in radar backscatter versus wind speed. This means that there is a difference between the wind speed necessary to generate gravity-capillary waves of sufficient strength to cause measurable radar backscatter compared with the wind speed necessary to maintain gravity-capillary waves. This work is the first study of this question based on field data and is important for interpreting scatterometer images, where there is a lack of understanding of the relationship between radar backscatter and wind at low wind speeds.

TRANSITIONS

Algorithms for extracting information on the atmospheric boundary layer from SAR images sometimes need information from other remote sensors to give robust and well-constrained estimates of that information.

RELATED PROJECTS

A closely related project includes my recently funded study by the National Science Foundation to look at the signature of atmospheric turbulence over Lake Michigan in simultaneous SAR imagery and in situ turbulence measurements.

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